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Liu, Q., Fusco, V., Linton, D., & Zelenchuk, D. (2014). *Frequency Scanning Antenna for Target Location Applications*. Paper presented at 8th European Conference on Antennas and Propagation, EuCAP 2014, The Hague, Netherlands.

**Document Version:**  
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# Frequency Scanning Antenna for Target Location Applications

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**Abstract**—We show how a high dispersion composite right/left-handed (CRLH) metamaterial leaky wave antenna can be operated both for scanning surveillance and for null tracking. The antenna presented, unlike previous leaky wave scanning antennas, requires only a narrowband frequency excitation range, 450MHz for  $-68^\circ$  to  $+27^\circ$  scanning including broadside for 2GHz center frequency operation. A design methodology for antenna synthesis is presented and experimental results based on a 2GHz antenna are presented. The resulting antenna should find application in RFID localization equipment.

**Index Terms**—leaky wave antenna, metamaterial, target location.

## I. INTRODUCTION

Object tracking and localization have continuously been investigated because of its diverse applications including safety, security and various services. There are a large variety of technologies [1] used for determining the trajectory of a moving target or the presence of an object. Recently Radio Frequency Identification (RFID) systems [2] have been developed due to its low cost and technical capabilities. In order to reduce complexity beam steering antennas can be used. Low profile cost-effective antennas with the beam steering induced by shifting the frequency of the signal source exist [3]. However conventional frequency scanning array antennas have the disadvantage that even relatively small steering angles require a large frequency range thus violating the narrowband spectrum constraints based on these systems e.g. [4].

In recent years, new composite right/left-handed (CRLH) metamaterials have been proposed for CRLH leaky wave (LW) antennas [5]. This type of frequency-scanned LW antenna exhibits several advantages over traditional LW antennas; they can support a radiating wave under its fundamental mode of operation, have a simple feeding mechanism and can be made to exhibit continuous beam scanning from backfire to endfire including broadside. In this work we propose a new design based on a balanced CRLH transmission line (TL) intended as a low-profile, low-cost, capable of wide spatial angle frequency scanning induced through narrowband frequency tuning. Further we show how it can be operated to facilitate target location.

## II. CRLH TL DESIGN STRATEGY

A CRLH TL is implemented by inserting an artificial series capacitance  $C_L$  and a shunt inductance  $L_L$  into a conventional

TL, that has intrinsic series inductance  $L_R$  and shunt capacitance  $C_R$ . CRLH TLs are periodic structures built around a unit cell that can be modeled by an equivalent circuit represented in Fig.1 (a) [6]. At low frequencies  $\omega_1$  to  $\omega_0$ , the CRLH structure operates in the LH radiation region I and the wave propagates backwards; at high frequencies  $\omega_0$  to  $\omega_2$ , the CRLH structure operates in the RH radiation region II and the wave propagates forward. In the balanced case, [6], the CRLH structure radiates in the broadside direction at the transition frequency  $\omega_0$  as there is no discontinuity in the dispersion characteristic. The balanced CRLH metamaterial characteristics can be explained by dispersion diagram derived from the equivalent-circuit model shown in Fig.1 (b).

The radiation angle  $\theta$  [7] for the CRLH LW antenna at its fundamental mode is given by (1). Thus in principle by exciting the CRLH LW antenna over the frequency range  $\Delta\omega$  ( $\omega_1$  to  $\omega_2$ ), full range spatial scanning can be achieved by taking value  $\beta_0 = \pm k_0$ . Also by increasing the unit cell capacitance or inductance, the slope of the dispersive curves can be made to flatten and the radiating frequency range  $\Delta\omega$  will reduce. For example as shown in Fig.1 (b), the dispersive curve change from the dashed red line to dashed blue line after increasing the value of  $L_R$  and  $L_L$ . Therefore, more equivalent series and shunt reactance need to be introduced per unit length if the intention is to reduce the frequency bandwidth required for large spatial radiation range.

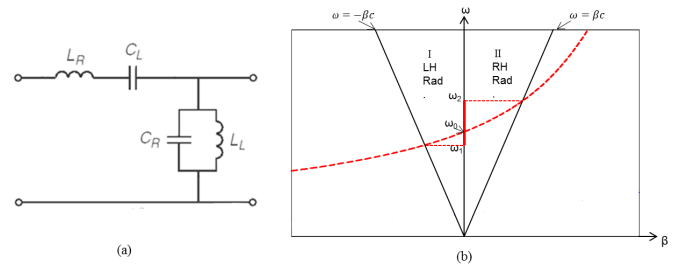


Fig. 1. CRLH unit cell: (a) equivalent circuit model (b) dispersion diagram

$$\theta = \sin^{-1} \left( \frac{\beta_0 + \frac{2n\pi}{d}}{k_0} \right) = \sin^{-1} \left( \frac{\beta_0}{k_0} \right) \quad (1)$$

In this paper a high dispersion CRLH TL unit cell is implemented using a distributed microstrip structure whose

equivalent circuit model parameters are extracted using S-parameters obtained from full-wave simulation. By inserting additional lumped inductors into the unit cell we realize a composite CRLH structure incorporating both distributed and surface mount chip, SMT, components.

### III. DESIGN OF THE NARROWBAND WIDE SPATIAL SCAN ANGLE CRLH TL UNIT CELL

#### A. Unit Cell Distributed Structure and Parameter Extraction

The distributed part of the unit cell is implemented on microstrip using printed interdigital capacitors which provides the required series capacitance  $C_L$ . Magnetic flux is generated by the current flow in the distributed capacitor adds to the series inductance  $L_R$ . Shunt capacitance  $C_R$  is generated between the trace and ground plane. The unit cell equivalent circuit for the structure in Fig. 2 (a) is shown in the Fig. 2 (b). Each side of the symmetric distributed unit cell contains five pairs of digits with widths of 0.3 and 0.2 mm spacing when realized on Rogers RT/Duroid 5880 with dielectric constant  $\epsilon_r = 2.2$  and thickness  $h = 1.57$  mm.

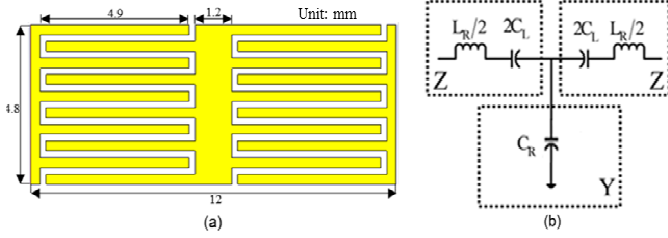


Fig. 2. (a) Layout and (b) equivalent-circuit model of the distributed CRLH unit cell

The parameters of the circuit model in Fig. 2(b) can be extracted using ABCD matrices from S-parameters obtained from a full-wave electromagnetic simulation tool such as CST. The extracted LH and RH parameters were  $C_L = 0.7$  pF,  $L_R = 2.4$  nH, and  $C_R = 1.4$  pF for the unit cell of Fig. 2.

#### B. Full unit cell and dispersion diagram

Next three SMT inductors were attached to the interdigitated structure in order to increase both the series and the shunt inductances of the cell. The dimensions of the full cell shown in Fig. 3 (a) are 4.8 mm \* 13.6 mm and the equivalent circuit now becomes that in Fig. 3 (b), with  $Z(\omega)$  and  $Y(\omega)$  expressed in equation (2). The value of lumped inductors  $L_{R1}$  and  $L_L$  was chosen to meet the balanced condition in (3) and broadside radiation at the required transition frequency  $\omega_0$ , (4).

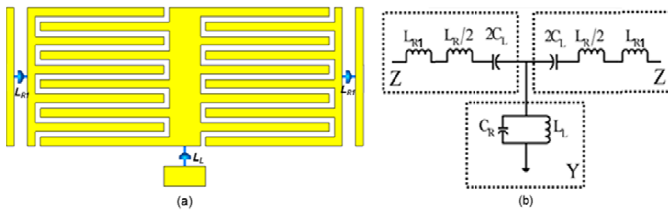


Fig. 3. (a) Layout and (b) equivalent-circuit model of the full CRLH unit cell

$$Z(\omega) = \frac{1}{2} \left( j\omega(L_R + 2L_{R1}) + \frac{1}{j\omega C_L} \right) \quad Y(\omega) = j\omega C_R + \frac{1}{j\omega L_L} \quad (2)$$

$$(L_R + 2L_{R1})C_L = L_L C_R \quad (3)$$

$$\beta = \beta_R + \beta_L = \omega_0 \sqrt{(L_R + 2L_{R1})C_R} - \frac{1}{\omega_0 \sqrt{L_L C_L}} = 0 \quad (4)$$

To achieve the broadside radiation at 2GHz, the calculated SMT inductor values were  $L_{R1} = 3.3$  nH and  $L_L = 4.5$  nH. The unit cell dispersion diagram based on the extracted parameters is plotted in Fig. 4. It can be seen that the LH radiation region is from 1.7 to 2GHz and the RH region is from 2 to 2.5GHz.

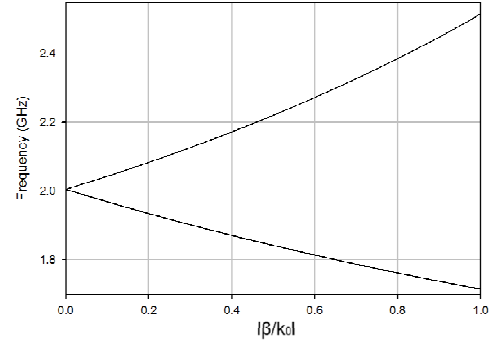


Fig. 4. CRLH dispersion curve calculated with the extracted parameters ( $L_R = 9$  nH,  $C_L = 0.7$  pF,  $L_L = 4.5$  nH, and  $C_R = 1.4$  pF)

### IV. ANTENNA STRUCTURE AND CHARACTERISTICS

A symmetric 15 unit-cell microstrip CRLH TL based on Fig. 3(a) was fabricated. The entire circuit was implemented on Rogers RT/Duroid 5880 with dielectric constant  $\epsilon_r = 2.2$  and thickness  $h = 1.57$  mm, Fig. 5. The total length of the structure is 21.4 cm. Simulated and measured reflection coefficient are compared in Fig. 6.

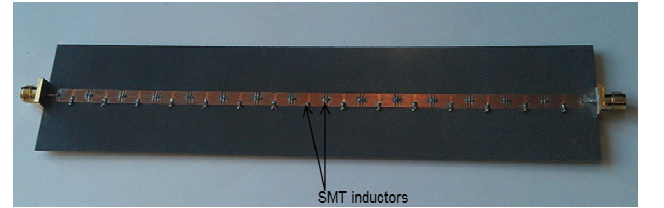


Fig. 5. 15-cell prototype of the CRLH LW antenna

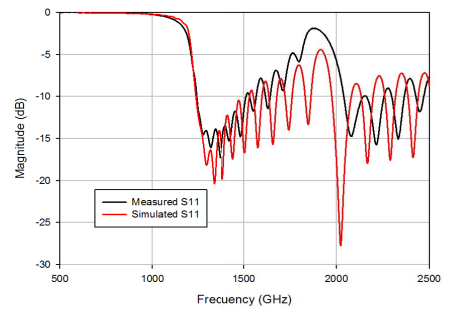


Fig. 6. Simulated and measured reflection coefficient

Simulated and measured elevation radiation patterns were normalized, in Fig. 7. For simulated patterns, continuous scanning from -58 degrees to +32 degrees is obtained from 1.7 to 2.25GHz with broadside radiating at 2GHz; while for measured patterns, continuous scanning from -68 degrees to +27 degrees is obtained from 1.7 to 2.15GHz with broadside radiating at 2GHz. The measured results demonstrate backward, broadside, and forward scanning and verify the simulation results.

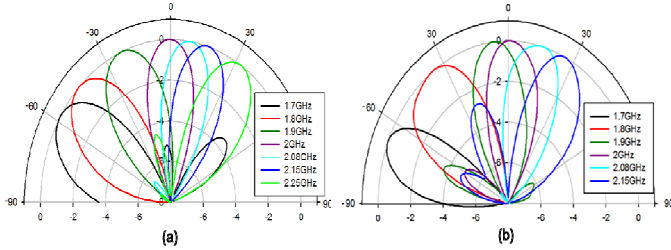


Fig. 7. (a) Simulated and (b) Measured normalized elevation radiation patterns

## V. ANTENNA FOR TARGET LOCATION APPLICATIONS

The antenna can be used for target location applications. Single sided operation allows scanning for electronic location without physical movement. If the antenna is fed with equal-amplitude/phase signals from both ends with the same frequency, Fig. 8 (a) two counter-scanning beams can be formed. Based on this, a target angle detection system can be established by turning the antenna around its physical center. By recording the received power against the turning angle the object can be tracked by null pointing. If we assume that the excitation current entering the right hand side of the antenna is positive then it will traverse an angle  $\phi$  by the time it reaches the physical center of the antenna. Excitation current applied at the left hand port is 180 degrees out of phase with respect to the right hand side applied current and at the center position it is at angle 180 degrees plus  $\phi$ . Thus the radiation from both sides of the antenna totally cancels along the broadside direction resulting in the observed null.

The measured radiation patterns at three frequencies are shown in Fig. 8 (b). It can be seen that two symmetric beams present at each frequency. Also it can be seen that as excitation frequency changes the antenna sends out different beams with different degrees of overlap. So at the null pointing angle target azimuth can be found. Also the target range can be calculated based on the path equation by relating minimum discernible signal to range by projecting different power levels along the null. The latter is achieved by varying the degree of overlap in Fig. 8 (b).

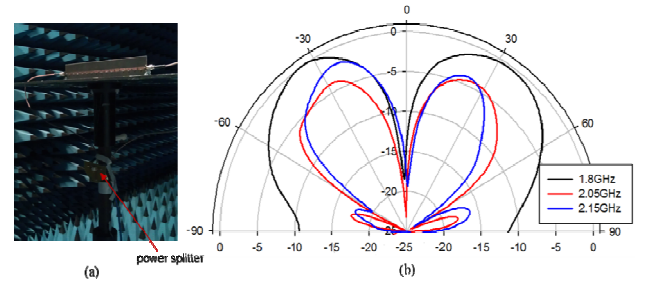


Fig. 8. (a) Measurements setup, (b) Measured radiation patterns in decibel scale at different frequencies

## VI. CONCLUSIONS

We have shown a synthesis approach which allows a microstrip CRLH antenna to operate in conventional scanning mode in forward and backward half spaces. In addition we have shown that the antenna can be operated such that it can project a null along antenna broadside whose depth can be varied. This facilitates target azimuth and range location. Unlike previous leaky wave scanning antenna the structure presented here requires a very narrow range of excitation frequencies allowing its potential use within the narrow spectrum available to RFID and ISM applications.

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